

Instrumented Citrus Production

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Abstract

Despite the notable technological support that has made Precision Agriculture feasible around the world, there are still opportunities for the development of instrumentation and automation in this area. These opportunities are more plentiful considering perennial crops and the traceability of agricultural products. Precision Agriculture has been developed more intensively for grains, which gives more opportunity for the development of technological tools for site-specific management of perennial crops, like citrus. Besides, the traceability of fruits is an immediate and strategic necessity in order to face non-economical issues for exporting, like phytosanitary measures. Therefore, for developing countries like Brazil, it is very important to develop technologies to identify the origin and history of fruit in the market chain for its major exporting products. For the last five years, at the Embrapa Agricultural Instrumentation Center in Brazil, some of these opportunities have been explored in order to start the development of an information system and associated tools to make possible the integration of traceability and the site-specific management system for perennial crops. The use of sensors, fixed and on-board instrumentation, wired and wireless networks, and advanced methodologies have been applied for precision agriculture and traceability for citrus. The main problems that have been studied are: phytosanitary control, spraying control, automation of fertigation, and evaluation of product quality.

INTRODUCTION

According to the Food and Agricultural Organization (FAO, 2005), from 2000 to 2004, Brazil was responsible for about 20% of the citrus production in the world. This number has not changed much during the last years. The production area is concentrated mostly in São Paulo State (85%). There are 700 thousand ha producing about 15 million tons of oranges a year. Despite those important numbers, the average productivity is 22 ton/ha, which can be considered low compared to Florida's productivity in the USA. This low productivity is associated with many different factors:

- Spreading of plagues and diseases with the expansion of planted area;
- No irrigation for most orchards;
- Narrow genetic base; and
- Lack of technological support.

Besides this, the production costs have increased, generating economical and social issues like unemployment and rural migration. Believing that the site-specific management and an instrumented citrus production could help to overcome this situation,

in 2003, a project entitled "Agrobusiness in the Information Society: Exploring Opportunities in Citrus Production" was started by the Embrapa Agricultural Instrumentation Center and its collaborators. This project's main objective is to explore opportunities in the development of instrumentation to bring the Brazilian citrus production into the information society with the practice of Precision Farming and traceability.

More specifically, the plan called for:

- The development of sensors and systems to acquire georeferenced information from the environment and crop in a frequent, efficient, reliable and economically feasible way;
- The implementation of transmission means to make possible the traceability and analyses of georeferenced information from the environment and crop; and
- The development of methodologies assisted by electronic systems to make use of georeferenced information from the environment and crop.

MATERIALS AND METHODS

The project was conducted as on-farm research in a pilot area of 25 ha (500 m x 500 m) on the Maringa farm, a private property of the Fisher Agropecuaria group. It was started in 2002 when the orchard was 12-year-old Valencia trees. A drip irrigation system had just being installed. The total farm area was around 2000 ha. In the following paragraphs, each planned activity is briefly described to this point in time.

RESULTS AND DISCUSSION

Origin and Yield Maps

When a truck gets to a factory or a packinghouse, the usual information it carries is the farm and eventually the plot where the oranges come from. The objective of this activity is to establish a more precise origin for the fruit in a truck, informing also from which exact trees the fruits were picked.

Harvesting oranges is totally manual. The picker carries a small bag and transfers the harvested oranges from it into a big bag located aside the grove rows. After this, the big bags are loaded into trucks. Radio Frequency Identifier (RFID) tags were installed at each tree in the pilot area and also in the big bags and in the trucks. Rewritable RFID tags were used for the big bags and the trucks. During the harvesting process, the picker uses a data collector to transfer the tree's ID to the big bag. Next, for each big bag loaded into a truck, its rewritable tag content is transferred to the truck RFID unit. Doing so, it is possible to map the truck's origin and the yield for the pilot unit area (Fig. 1). The yield map resolution is 50 m in average, and it is calculated on the number of trees used to get a truckload.

No special training was given to the pickers in order not to interfere with the original harvesting process: picking following a row. That is why the maps take the shape of the grove rows (Fig. 1b). Training the pickers, based on planning the picking in a square basis, would improve the method resolution. Tagging the entire farm may be too expensive. Nowadays, with GPS receiver price going down, this tag method is not cost effective.

Hydric Stress Map

São Paulo region has a dry season that can last as long as four months. That helps to state a desired hydric stress for the orange trees to increase the grove production. For irrigated farms, it is possible to control the degree of hydric stress. Usually this control is done by a subjective observation of some elected trees that allows classifying their hydric situation in three classes: 1) No stress; 2) Average stress and 3) Total stress. When most of them reach the Total stress condition, the irrigation system is started. The objective of this work was to establish an instrumented method to map the hydric stress classes, and, through this map, to calculate the number of trees in the Total stress condition.

By using a hand-held active sensing device, the Normalized Difference Vegetation Index (NDVI) is obtained and compared to the subjective evaluation of each hydric stress condition (Fig. 2). Observing that the numbers are significantly different, at least for the No stress and Total stress condition, the next step was to mount a GPS and the hand-held sensing device over an ATV (All Terrain Vehicle), both connected to a portable computer to map the NDVI (Fig. 3).

This method of mapping NDVI is not properly tested to control the irrigation system. Besides the comparison to a subjective evaluation, it should be compared to another measurable property. A future step in this activity is to establish a correlation to the NDVI and the leaf water potential, measured by the pressure chamber method. Even if it proves to be not very accurate, mapping the NDVI would be a better choice instead of the current subjective evaluation in order to better control the degree of hydric stress.

Site-Specific Irrigation System

The largest part of the citrus production area in Brazil is not irrigated yet. Due to recent spreading of some new diseases, like the Sudden Death, this scenario is changing and most groves tend to be irrigated. Therefore, water source conservation methods should be applied. For this activity, a wireless fixed instrumentation (sensor and actuator network) and software tools to site-specifically irrigate perennial crops were developed (Torre-Neto et al., 2005). This system came out of an initial effort to develop variable-rate microsprinkler irrigation in Florida, USA (Torre-Neto et al., 2000).

The system operates in a star architecture and is based on a proprietary communication protocol. It is composed by Sensor and Actuators Nodes, one or more Field Stations, a Base Station and an Installation Kit (Fig. 4). At the Base Station, a personal computer runs the control program, which has geographical information system (GIS) functionalities and works on a space-temporal database. The Nodes developed so far are: a) a combined soil moisture and soil temperature sensor and b) a combined latching solenoid actuator and flow meter. An ion selective Node to measure soil nutrients has been developed (Artigas et al., 2003; Lemos et al., 2004).

Forty-nine soil sensors, in a 7 x 7 grid pattern distribution, were installed in the Pilot Unit. At every hour, soil moisture maps are obtained (Fig. 5). The expected results from those maps are to identify different needs of irrigation water for the grove in order to establish management zones that reflect the spatial variability for the combination of different factors like soil texture and terrain topography. The piping system has to be installed or modified according to these zones. The Base Station software allows for controlling automated valves and establishing control loops for each individual zone.

The system was conceived to be low-cost, reliable, and compatible with contemporary local citrus production practices. The big challenge is to assure that the Node battery lasts long enough (a couple of years) in order to achieve system feasibility. Future steps are evaluating a Zigbee-based version, maximizing the operation time for the Node battery, and comparing the water consumption against a conventional automated system.

Soil Physical Properties

Chemicals are often applied in citrus production as phytosanitary measures. This heavy traffic of machinery causes soil compaction, which affects root growth and water flow. The objective of this activity is to determine the soil strength by measuring the soil penetration resistance and simultaneous water content.

Automated pneumatic equipment was developed to be adapted to a truck or on a small tractor in order to allow on-the-go measurements (Fig. 6). This equipment is based on a soil cone penetrometer combined with soil moisture measurements as proposed by Vaz and Hopmans (2001). Instead of a TDR, a capacitive sensor embedded close to the cone, along the penetrometer rod, was used. The 40 kg unit is versatile and the electronic system allows computer connection. This equipment was not developed exclusively for

Citrus. The prototype has been tested for sugarcane, its primary target crop (Fig. 7). The next step is to evaluate it in the Pilot Unit.

Quality Evaluation

The electronic tongue has been successfully used for beverage analysis worldwide (Ciosek and Wróblewski, 2007). In Brazil, this sensor has been used mostly for analyzing coffee quality (Ferreira et al., 2007). In this activity, the electronic tongue was evaluated to analyze orange juice. An array of seven sensorial units composed by ultra-thin films produced with non-structured conducting polymers was tested to brand recognition. As shown in Figure 8, using the Principal Component Analysis method, it is possible to distinguish four different kinds of ready-to-drink juice (brands A, B, C, and D), two kinds of reconstituted juice (brands E and F), and two kinds of fresh juice (L Lima and L Pera).

Optical Instrumentation

Sudden Death is an important Citrus disease in Brazil. From 1999 to 2004, it caused the death of more than 1.5 million orange trees (Roman et al., 2004). The usual method to identify contaminated trees is the observation of dull leaves and yellowing in the internal part of the stem. As an alternative for this method, induced fluorescence analyses were carried out with samples from infected and healthy trees (Terencio et al., 2005). The result is a spectroscopic index obtained from leaves that allows the identification of Sudden Death disease in 90% of the cases (Fig. 9). Portable equipment was developed with specific computer software that is capable of providing this fluorescence spectroscopic index within a few seconds (Fig. 10). The equipment has been tested in the laboratory. The goal is to prepare a mobile lab to carry out measurements in the field. The rapid detection of the disease makes possible a quick decision, diminishing losses for the citrus producers.

Image Processing

The objective of this activity is the development of methodologies and related software tools to identify diseases by aerial and terrestrial images. An Unmanned Aerial Vehicle (UAV) has been used to acquire the aerial images (Trindade et al., 2004). As described by Jorge et al. (1998), Spectral Variations and Neural Networks have been used to identify infected trees (Fig. 11). For terrestrial images, the focus has been on fluorescence images to identify Sudden Death (Fig. 12).

CONCLUSIONS

The results of this work are in different stages and can be considered mostly initial efforts. This project is a startup for several other proposals to promote Instrumented Citrus Production guided by the site-specific management and product traceability in Brazil. Some of these proposals are already approved running projects.

ACKNOWLEDGMENTS

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Figures

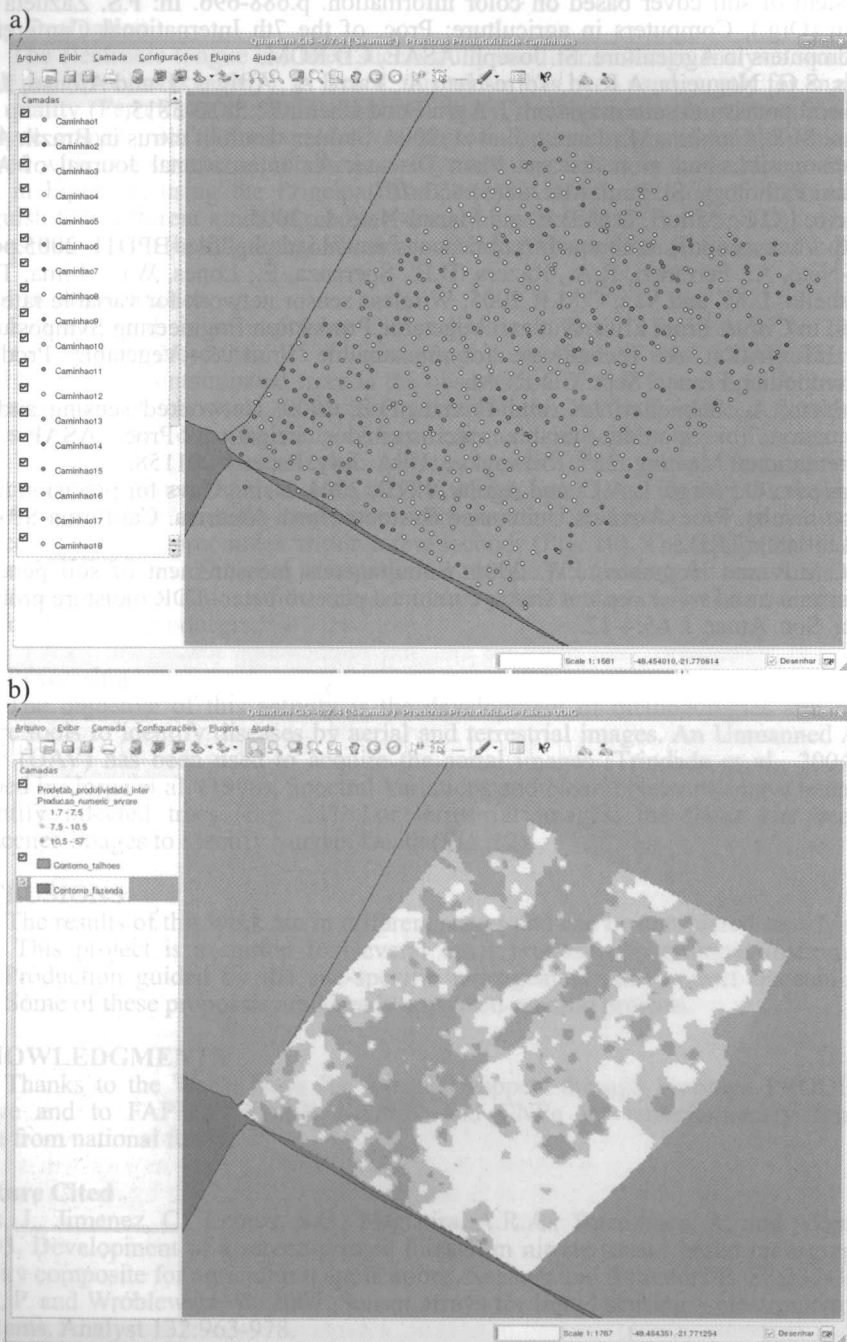


Fig. 1. a) Origin map showing the trees for each truck load and b) yield map in box/tree within a 50 m average resolution (one box = 40.8 kg).

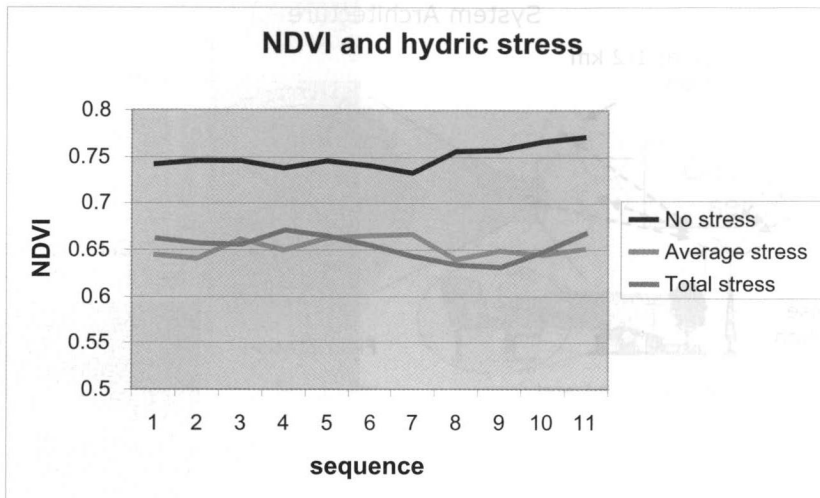


Fig. 2. Normalized difference vegetation index (NDVI) obtained for three subjective classes of hydric stress.

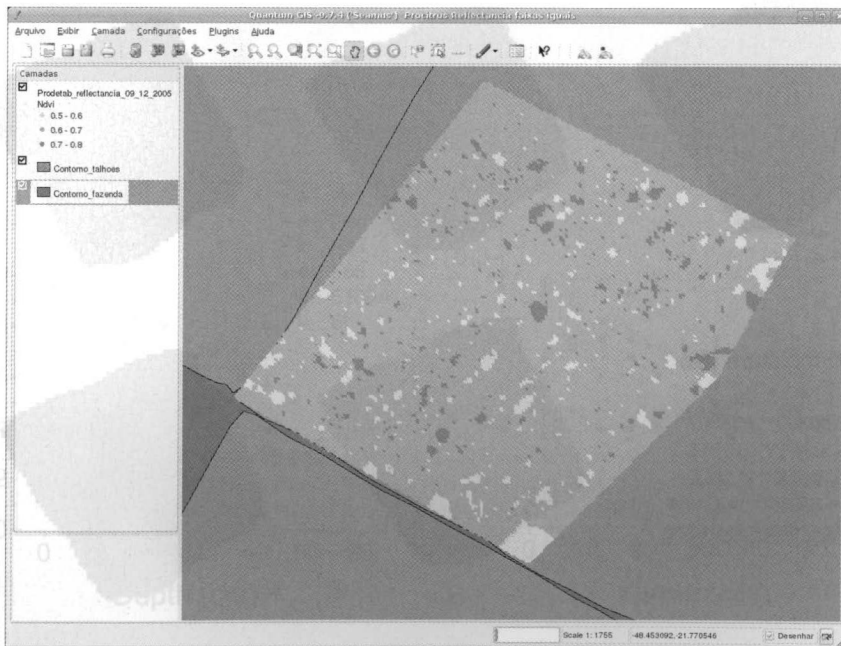


Fig. 3. NDVI map indicating that most of the grove trees have not reached the Total stress condition (NDVI < 0.7).

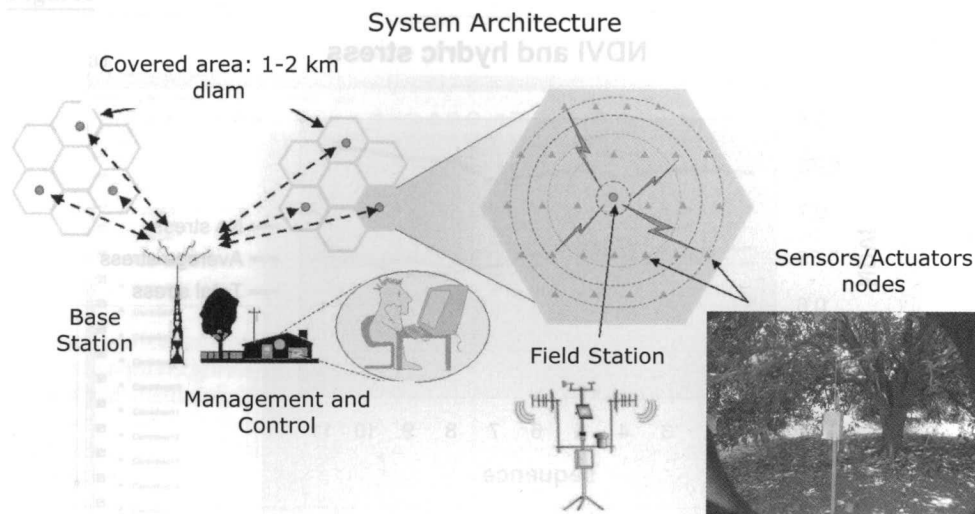


Fig. 4. Wireless sensor and actuator architecture developed for a site-specific irrigation system in perennial crops.

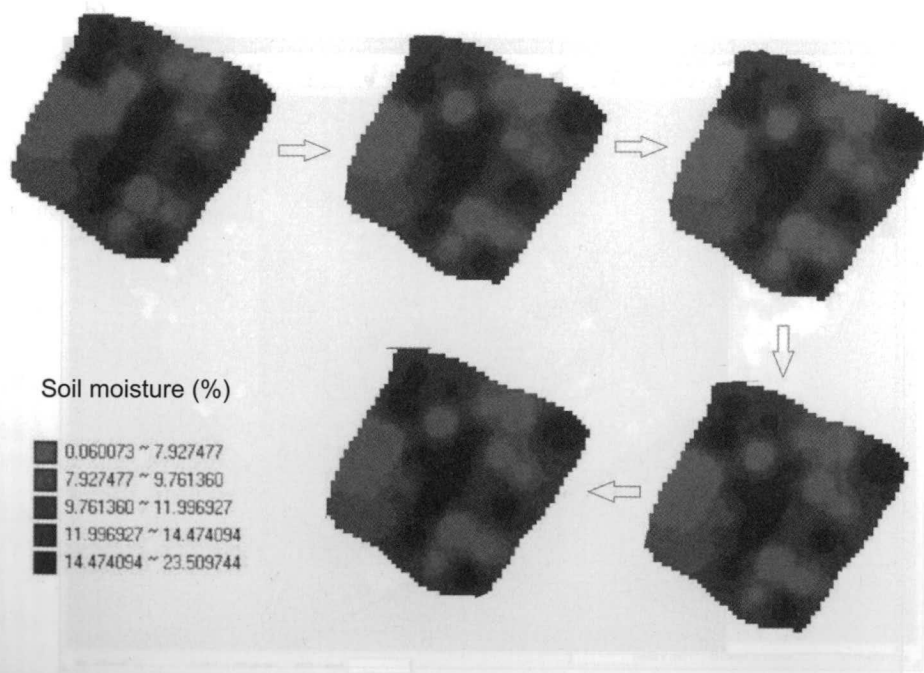


Fig. 5. Sequence of soil moisture maps at 25 cm depth, obtained by a 7 x 7 grid of wireless sensors spaced 40 m from each other at one hour time intervals.

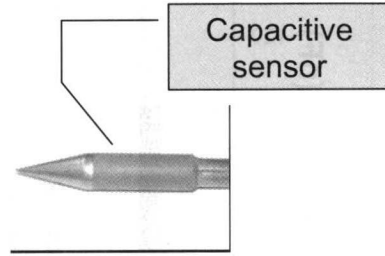


Fig. 6. Pneumatic on-the-go equipment developed to measure simultaneously the soil penetration resistance and moisture.

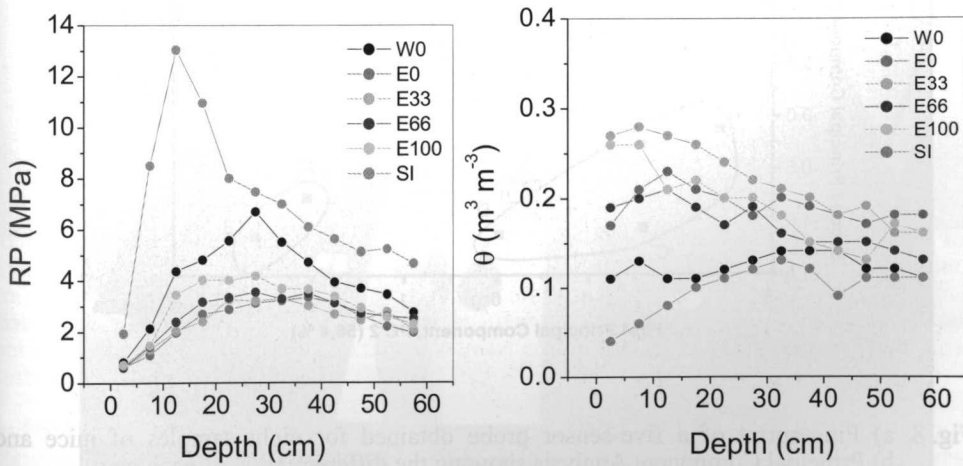


Fig. 7. Typical data obtained from six different spots with the combined soil penetration resistance and moisture probe.

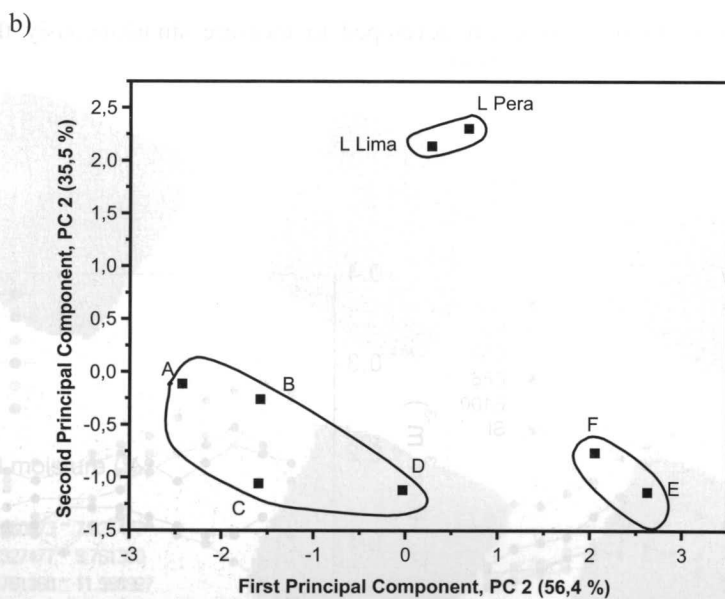
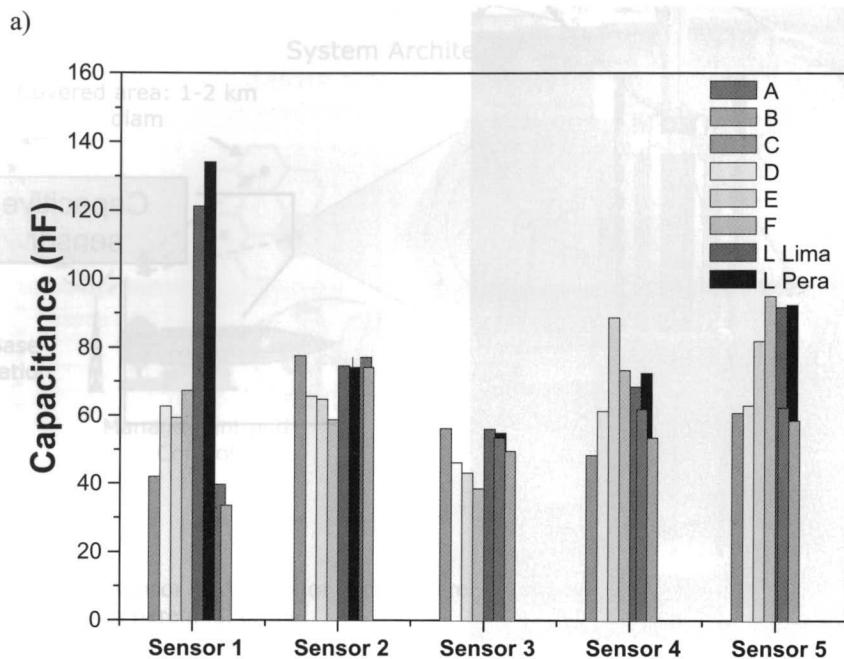


Fig. 8. a) Fingerprint of a five-sensor probe obtained for eight samples of juice and b) Principal Component Analysis showing the differentiation of each one.

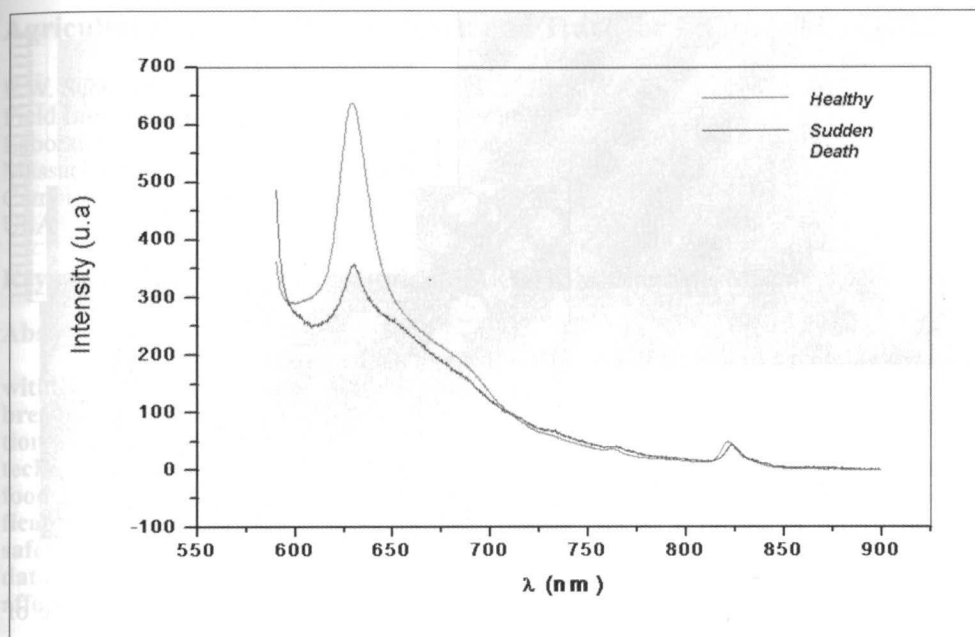


Fig. 9. Fluorescence spectroscopy of leaves from orange trees used to identify the Sudden Death disease.

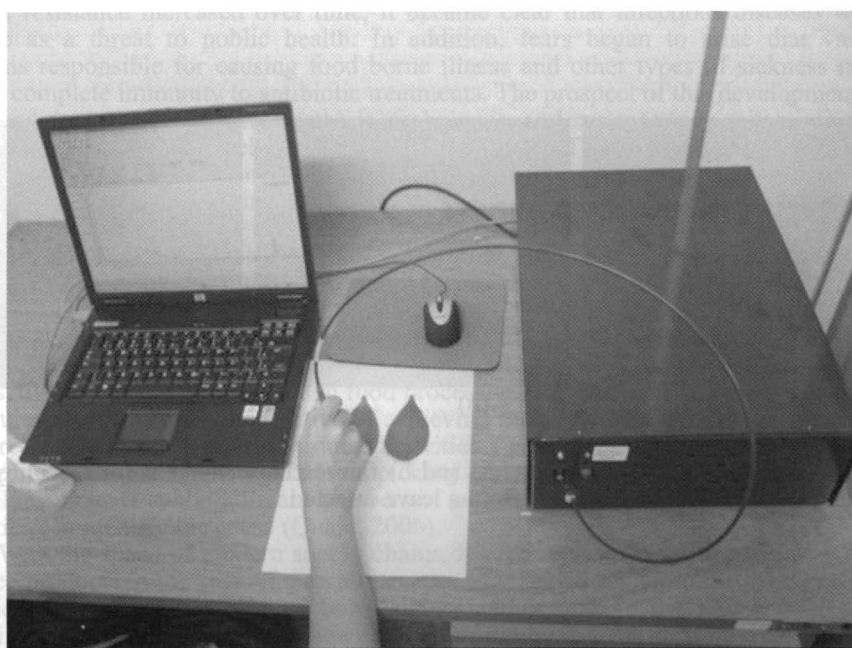


Fig. 10. Portable spectrometer and software developed for diagnosis in the field.

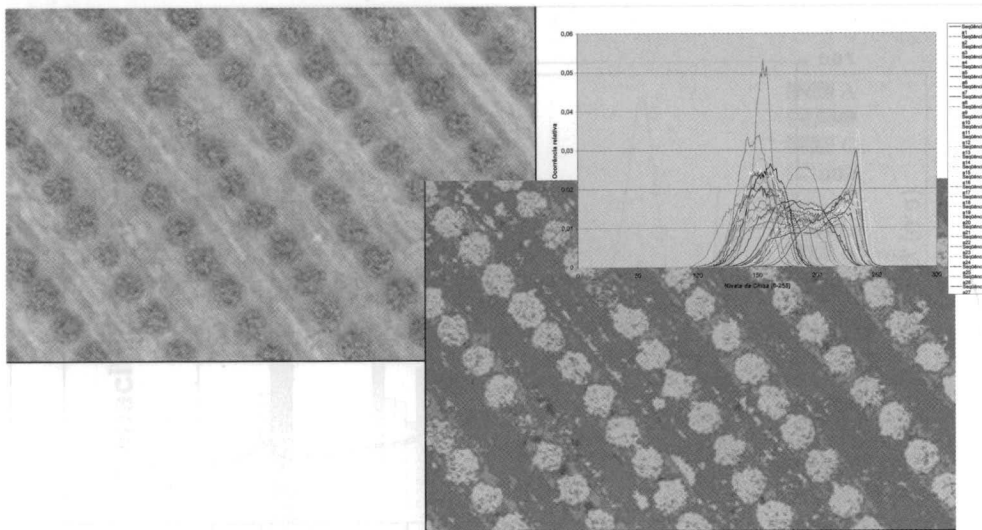


Fig. 11. Image acquired at 100 m altitude by an Unmanned Aerial Vehicle, a sample of its spectral variation and processed image by neural network.

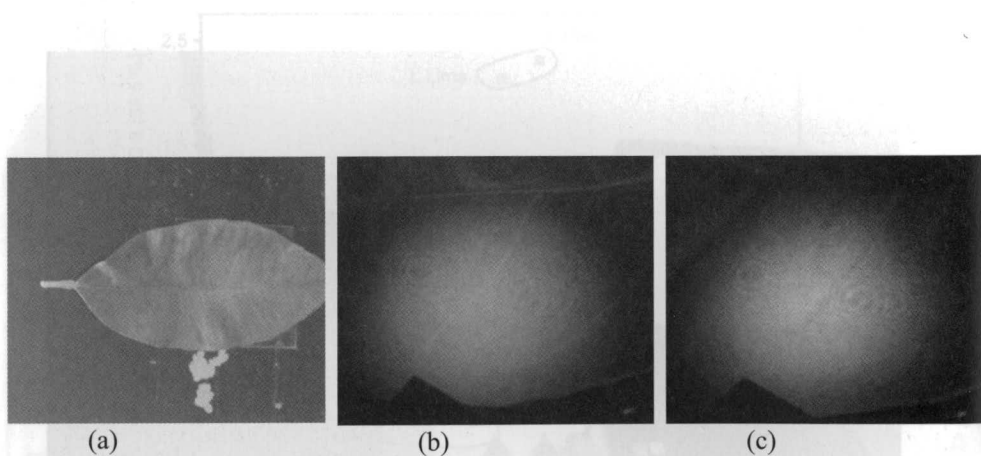


Fig. 12. a) Delimited region of interest and b) fluorescence image from a healthy leaf and c) fluorescence image from a leaf infected with Sudden Death.